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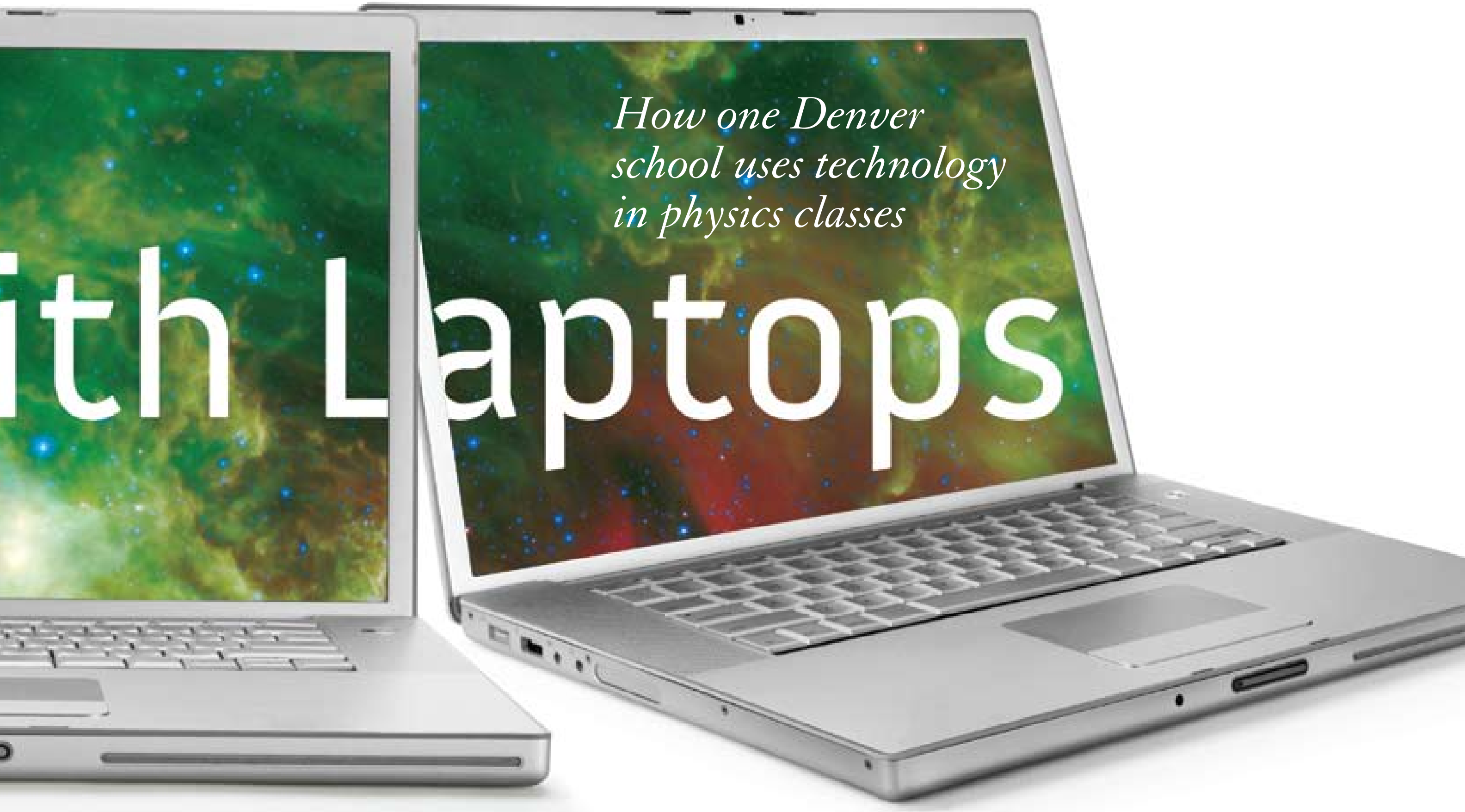
The declining cost of computers and wireless networks has made laptop programs more affordable than ever. At the same time, the internet resources available to teachers and students have grown exponentially in the 15 years since web browsers first became practical. As a result of these trends, growing numbers of students nationwide are provided with wireless laptops by their schools. In Maine, laptops have been given to all middle school students since 2001 and many of the state's high schools support 1:1 laptop programs. (In 1:1 programs, every student is provided with a personal computer to use during the school year.) In Pennsylvania, more than 500,000 high school students have been provided with laptops in English, social studies, math, and science classrooms as part of the state's "Classrooms for the Future" program. Many other states and districts have schools that support 1:1 laptop programs, and thousands of schools have purchased mobile carts equipped with class sets of wireless laptops.

In this article, we describe how laptops have been used to teach physics at the Denver School of Science and Technology (DSST). In 2004, DSST became the first public high school in Colorado with a 1:1 laptop program. Laptops are used daily by both teachers and students at this charter school, where a large percentage of students come from low-income families (see "About DSST," p. 25). The school's successful experience with laptops provides an example for the thousands of science teachers across the United States who now have the opportunity to use computers with students every day.

Laptops in the classroom

Creating a rigorous curriculum for *every* child demands that teachers differentiate both learning activities and assessments. Using computers can help make lessons more engaging and can challenge students at their own level—while providing instant feedback to both the teacher and students. At DSST, it is not the individual use of laptops that enhances students' education, but the entire set of laptop applications used together to support student learning.

To illustrate how DSST students use laptops, this article focuses on a weeklong unit about electric circuits in a ninth-grade physics course. The school has adopted a "physics first" approach—in that all ninth graders enroll in the same level of physics. Differentiation within the classroom supports students at varying levels of math proficiency. The school's physics teachers and students make extensive use of the laptops, but responses to a survey of all DSST students found that the majority report using their laptops daily in English, humanities, history, math, Spanish, and other science classes as well. Data collected from surveys, interviews, observations, and other sources show that laptops are thoroughly integrated into the school's curriculum (Zucker and Hug 2007). All of the school's science classes use laptops extensively and in



a similar fashion—by incorporating electronic textbooks, inquiry-based simulations, probes for data collection, spreadsheets for data analysis, and online assessments. The following sections illustrate how one ninth-grade physics class uses laptops over the course of a week.

Teaching about circuits

During the sample week presented in Figure 1 (p. 24), students gain an understanding of parallel and series circuits and the relationships among current, resistance, and voltage in these circuits. Throughout the week, they also develop inquiry skills, which are emphasized at DSST. Students use their computers daily for many purposes, including warm-up exercises, inquiry activities, and assessments (Figure 1).

In ninth-grade physics, each class meeting includes a closing assessment, in which students respond on their laptops to determine whether or not the day's learning objectives have been met. Higher-level activities are offered, or required, for students needing more of a challenge, while extra resources are provided for lower-achieving students. The last class of the week offers flexible grouping at two levels to further challenge some students and reteach missed objectives to others.

By design, physics teachers—and all of the science teachers at DSST—use a combination of hands-on laboratory activities and online inquiry activities. Students are expected to learn both traditional laboratory skills and computer-based skills.

Inquiry activities

One set of online activities often used by DSST's physics teachers was developed at the University of Colorado at Boulder under the direction of Nobel Prize–winner Carl Wieman. These cost-free, research-based simulations encourage the discovery of physics concepts through experimentation and visualization. The Physics Educational Technology (PhET) simulations (see "On the web") minimize or eliminate the distractions and errors that can occur when using laboratory equipment and allow students to quickly test hypotheses and immediately check results (Wieman and Perkins 2006). The activities can be used anywhere there is internet access and can also be stored on the laptops.

After a bit of simulation instruction, students are able to work independently. In Monday's lesson (Figure 1), students use the PhET Circuit Construction Kit (CCK) simulation to explore how to build a circuit that will make a lightbulb light up. With the kit, students are able to build and test direct current (DC) circuits they have designed without the danger of overloading the circuit. Furthermore, the simulation offers the opportunity to "see" the electrons moving through the components.

FIGURE 1

Lesson plans on electric circuits in ninth-grade physics.

	Monday	Tuesday	Wednesday	Thursday	Friday
Learning objectives	◆ Determine what makes current flow through a circuit. ◆ Apply the terms *voltage*, *current*, and *resistance* to a circuit.	◆ Determine the relationships among voltage, current, and resistance in a simple circuit. ◆ Solve problems using Ohm's law.	◆ Determine how well a real circuit obeys Ohm's law.	◆ Build working circuits. ◆ Identify differences between parallel and series circuits.	◆ Solve problems involving parallel and series circuits, or combinations of each.
Warm-up activity	◆ Respond in journal to open-ended questions that put week's lesson in context and create the "need to know."	◆ On paper, draw three different circuits that you think would make a lightbulb light up. Check your answers with the online CCK.	◆ Put homework answers into exam software on laptops to automatically check solutions.	◆ Solve several problems about lighting a room in a dollhouse. Discuss in small groups.	◆ Use spreadsheet to find your assigned group members. Download group's documents and start activities.
Main activities	◆ Complete inquiry activity using virtual circuit construction kit (CCK) from PhET website (see "On the web).	◆ Use CCK and Ohm's law simulator from PhET website to practice solving problems with guidance.	◆ Use probes with the laptops to measure how current changes as resistance or voltage changes in a real circuit.	◆ Complete inquiry activity using CCK and real circuit boards to explore properties of parallel and series circuits.	◆ *Level 1:* Relearn missed objectives. Find current in a simple series or parallel circuit. ◆ *Level 2:* Find current in more complex circuits.
Closing assessment	◆ Take laptop quiz testing learning objectives.	◆ Take laptop quiz testing learning objectives.	◆ Discuss lab results as a class.	◆ Take laptop quiz on the week's objectives.	◆ Answer questions from Monday's warm-up activity. Discuss as a whole class.
Laptop homework	◆ In a word processing document, describe how to build a circuit that lights a bulb.	◆ Answer questions and problems on Ohm's law and check answers using computer simulation.	◆ Complete lab analysis and prepare report with a word processor.	◆ Read textbook section on parallel and series circuits and use its interactive features.	◆ Solve problems with circuits. Use digital text and its simulations to study for a test.

(**Note:** Class periods are 55 minutes long on Wednesday and 75 minutes long on other days.)

With over 70 simulations, the PhET website (see "On the web") is a valuable resource for teaching not only physics, but also biology, chemistry, Earth science, and math. For example, a simulation on gas properties lets chemistry students explore the relationships among temperature, volume, pressure, and gravity in an ideal gas. In some cases, there is evidence that these simulations can be more effective learning tools than laboratory equipment (Finkelstein et al. 2005).

During the sample week in ninth-grade physics—and in all DSST science classes—students use class sets of data-collection lab probes, which can be attached to the laptops. Using commercially available temperature, pH, motion sensing, voltage, conductivity, and other probes, students can test hypotheses and find relationships in hands-on experiments. The graphing software on each laptop makes analysis more immediate, and students learn to correct their own data-collection techniques to get better quality data. For example, on Wednesday of the sample week (Figure 1), students measure the current in a simple series circuit as the resistance increases; in the electrostatics lessons the previous week, students used quantitative charge probes to measure charge by induction. Both 9th- and 12th-grade physics students use their laptops to collect and analyze data about once every week.

The 12th-grade physics students also use a commercial vendor's electronic textbook that is stored on their laptops. The text includes a wide variety of electronic physics simulations, animations, and interactive problem-solving tutorials. Digital textbooks make it easier to scaffold lessons for students who need extra help (e.g., students can get hints that are initially hidden from view) and differentiate instruction in other ways.

Computer simulations and animations are powerful learning tools. In a survey of DSST students, one student wrote, "I believe that the most helpful use of technology has been the use of technology to give us interactive lessons or lectures about specific topics. It makes it so much easier to understand a concept if you can see it happen in an animation."

About DSST.
An open enrollment, public school with a diverse student body, DSST accepts students based on a random lottery, not academic performance. The only restriction lies in the school's charter, which states that at least 40% of its students must qualify for free or reduced-price lunch (i.e., come from low-income families). Despite many of the incoming students' underdeveloped skill levels, every member of the school's first two graduating classes, in 2008 and 2009, was accepted to a four-year college. This was a remarkable accomplishment, given the city of Denver's overall graduation rate of only 52% and the diversity of the DSST student body—of the graduating class of 2009, 63% were a minority, 44% were considered low income, and 43% were the first generation to go to college. Of the 2008 senior class, 30% took an Advanced Placement (AP) physics exam, compared to about 3% of seniors nationally. Although DSST is not successful with every student who enters (some transfer out), and not every student completes an AP physics exam, its impressive statistics have persuaded Denver to authorize the development of four similar schools.

Differentiation and assessment

Computers are useful for assessing students quickly, and assessment data can then be used to differentiate instruction. DSST licenses software on each student's laptop that makes it easy to administer multiple-choice assessments and get results to both the teacher and the student. In physics classes, this exam software is used for everything from students' final exams to the closing assessments given at the end of class.

The exam software provides teachers with flexible grading and analysis tools. The assessments can be graded automatically (for multiple-choice questions) or manually (for short-answer or essay responses). Once assessments are graded, teachers can easily review quantitative reports on achievement for the entire class or for individual students. In this way, teachers can see how each individual student is progressing over time, or get a picture of how the whole class is doing on a specific skill. Item analyses on exams show the percentage of students correctly answering each question, and the number of students who choose each wrong answer. These tools give teachers a clear picture of how well students have met learning objectives.

Using the exam software or a spreadsheet, teachers can also create lists that group students by the skills they need to improve. Sometimes students are divided into groups within a physics classroom. At other times, two physics teachers split up classes so that one takes the higher-level students for a few days or weeks to challenge them further, while the other reteaches certain skills. Both types of flexible grouping are temporary—and later group assignments are made based on other assessments.

The exam software can also be used to assess closing questions at the end of class. For example, one of the closing questions for Monday's class (Figure 1) gives students a series of sketches of a battery, a lightbulb, and some wire and asks them to identify which configurations will turn on the lightbulb. Students take these tests and quizzes on their laptops and can review results and teacher-developed explanations immediately after they are finished. Students know how proficient they are according to college-readiness standards developed by the school that are linked to assessment items. Reports can also show students how they

are doing compared to other students (with scores listed by ID number to protect privacy).

With a laptop in each student's hands, it is easier to make multiple resources available for differentiated lessons. For example, in Friday's lesson (Figure 1, p. 24) students start class by downloading a spreadsheet compiled by the teacher with results from the previous day's lesson. The spreadsheet assigns students to groups, so they are able to download the activity guides and get to work. When working on lab reports, students use a rubric stored in a spreadsheet to determine which section of the report they need to work on most, and then look at the prepared exemplars and other electronic materials for preparing each section.

Students with laptops also have more tools at hand for creating products that demonstrate mastery of a concept. For one end-of-year project, physics students can choose to present their ideas in a variety of forms—using video, a brochure, a slideshow, lab reports, or traditional paper posters. The laptops support the use and creation of various media, and students can easily conduct research online and use computer-based simulations. Students also use spreadsheets, word processing, e-mail, and other software tools in conventional ways—but with 1:1 laptops these tools are used much more often. Documents of all kinds can be shared cheaply and efficiently, including exemplars, templates—such as those that can be used to write a high-quality lab report—and the daily closing assessments.

Alternatives to 1:1 laptops

The number of schools supporting laptop programs will continue to grow despite the fact that technical support, teacher professional development (an essential element of any laptop program), maintenance, repair, software, and other lifecycle costs create a significant price tag for these programs, and that evidence of their effectiveness is mixed (Zucker and Light 2009). Research often follows practice, rather than leading it. (Take, for example, charter schools, which have mushroomed despite the absence of a clear consensus among researchers about their impact.) Yet studies already show that many applications of technology help improve student learning (e.g., computer-based visualizations of scientific phenomena [AERA 2007], data-collection probes, graphing calculators, and certain software). In addition, thousands of up-to-date resources are available on the internet, and students using laptops have constant access to word processors, spreadsheets, and other powerful learning tools.

Most of the pedagogical approaches used to teach physics at DSST could be used in schools without a 1:1 laptop program by using carts with wireless laptops. "Clickers"—handheld devices that students use to beam responses to the teacher's computer—can provide some of the same benefits as the exam software on each student's laptop. A computer projector or interactive whiteboard allows a teacher to use simulations and animations for the whole class to see.

Although these alternatives are better than having no computers in the classroom, a 1:1 laptop program offers students the added benefit of evening and weekend access to their digital resources, which is particularly valuable for low-income students without access to personal computers at home.

Conclusion

With laptops in hand, all students can study from their electronic textbooks, review simulations, and complete data analysis for lab reports. This increased access to computers and information is one reason some policymakers support 1:1 programs as a means to eliminate the "digital divide." DSST and other successful laptop schools illustrate ways that computers, when used well, help students learn science using an array of powerful electronic tools. Personal laptop computers engage students; encourage independence; support differentiated instruction; and make assessment, communication, and other common teaching tasks more efficient. It takes time to learn how to teach well when every student has a laptop, but the majority of DSST's teachers consider the effort worthwhile. Fully two-thirds of them believe the laptops are "essential" to their teaching practice. ■

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On the web

PhET simulations: *http://phet.colorado.edu/index.php*

References

American Educational Research Association (AERA). 2007. *Science education that makes sense*. *Research Points* 5 (1): 1–4.

Finkelstein, N.D., W.K. Adams, C.J. Keller, P.B. Kohl, P.B. Perkins, N.S. Podolefsky, S. Reid, and R. LeMaster. 2005. When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Physical Review Special Topics: Physics Education Research* 1 (010103): 1–8.

Wieman, C., and K. Perkins. 2006. A powerful tool for teaching science. *Nature Physics* 2: 290–292. *http://phet.colorado.edu/phet-dist/publications/NaturePhysics_Final.pdf*

Zucker, A., and S. Hug. 2007. *A study of the 1:1 laptop program at the Denver School of Science and Technology*. Denver: Denver School of Science and Technology. *http://scienceandtech.org/documents/Technology/DSST_Laptop_Study_Report.pdf*

Zucker, A.A., and D. Light. 2009. Laptop programs for students. *Science* 323 (5910): 82–85.